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Prediction of Mechanical Properties of Hybrid Fiber Reinforced Polymer Composites

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Abstract— ***This work presents a systematic approach to evaluate and study the effect of process parameters on tensile flexural and impact strength of coir and bagasse fiber reinforced polyester-based hybrid composites and also predicts the properties of random oriented hybrid composites. The composite panel was fabricated using hand lay-up method to the size of 300mmx200mmx3mm with various weight percentage of natural fibers namely coir (10, 20 and 30 wt %) and bagasse (10, 20 and 30 wt %) combined with polyester resin. The mechanical properties testing such as tensile, flexural and impact strength were carried out for the samples cut from the fabricated composite panel to the dimensions as per ASTM standard. The significant contribution of mixing of fiber was determined by analysis of variance. The second-order polynomial curve fitting equations are modelled to predict the mechanical properties such as tensile, flexural and impact strength. Also scanning electron microscopy testing was conducted on tensile test specimen to find the fiber matrix interfacial adhesion.***

Keywords— Hybrid fibers, polyester, tensile strength, flexural strength, impact strength, ANOVA, SEM.

I. Introduction

Natural fibers are hair like material which is directly obtained from an animal, vegetable, or mineral source and convertible into nonwoven fabrics such as felt or paper or, after spinning into yarns, into woven cloth. In this research coir and bagasse were used as natural fibers and the polyester as resin material.

Coir fiber is obtained from the Outer layer of the fruit of Coconut tree (Cocos Nucifera L). This outer layer is called the coconut husk. The husk (exocarp) of the coconut consists of a smooth waterproof outer skin (epicarp) and fibrous zone (mesocarp). The mesocarp comprises of strands of fibro vascular bundles of coir embedded in a non fibrous paranchymatous "corky" connective tissue usually referred to as pith; which ultimately becomes coir dust. Bagasse, also called Megass, fiber remaining after the extraction of the sugar-bearing juice from sugarcane. The word 'bagasse', from the French 'bagage' via the Spanish 'bagazo', originally meant 'rubbish', 'refuse', or 'trash'. The chemical name of polyester resin is 1,3-Benzene dicarboxylic acid, polymer with 1,4-cyclohexane dimethanol, 2,2-dimethyl-1, 3-propanediol and 2,5-furandione. Its molecular formula is $(C_8H_6O_2, C_8H_{16}O_4, C_5H_{12}O_2, C_4H_2O_3)_n$. Ambient temperature cure unsaturated polyester resins provide the ability to produce high-quality, value added composite products.

In recent years, hybrid composites containing two or more fibers obtained considerable attention. Natural fibers are renewable, cheaper, support no health hazards and finally provide a solution to environmental pollution by finding new uses for waste materials.

II. Materials and Methods

In this investigation the coir and bagasse fibers were taken to reinforce with the polyester resin.

Chemical treatment

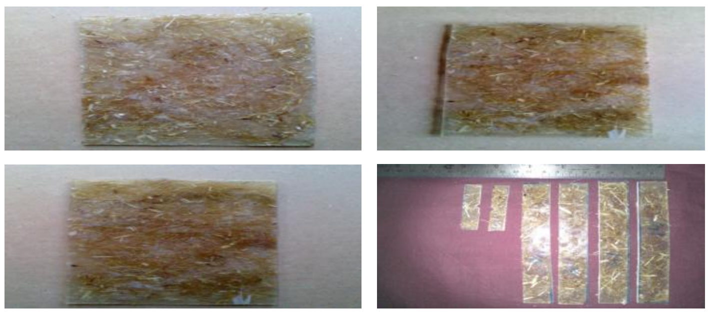
After the fibers were collected, the coir was allowed to undergo with the chemical treatment by using the 6-8% of NaOH with the distilled water. This treatment was used to remove the lignin content in the fiber. The lignin content may affect the Young's modulus of the fiber. So, the fiber was treated by using the NaOH.

Mould preparation

To prepare the composite, polyester resin was used as matrix material. The chopped coir and bagasse fibers hybrid composite sheets were manufactured by simple hand lay-up process in a mould. The mould was prepared to fabricate the test specimen. The dimensions of the mould were 300mmx200mmx3mm. Nine hybrid composites with different combinations of coir fiber content (10, 20 and 30 wt%) and bagasse fiber content (10, 20 and 30 wt%) were designed and produced. After the curing process, test samples were cut according to the sizes of ASTM standards. Fig.2.1 shows some of the moulds and the sample pieces.

Fig.2.1: Fabricated moulds and test specimens

III. Mechanical Tests



The samples of pre-fixed fiber content of produced hybrid fiber reinforced composites were investigated for their tensile, flexural and impact properties. Both tensile, flexural and impact strength tests were conducted for all the nine samples.

Tensile Strength Test

The tensile strength of the composites was measured with a universal testing machine in accordance with the ASTM D3039 procedure. The speed of the tensile testing machine is about

2mm/min. The tensile strength of all nine combinations is shown in Fig.3.1.

Flexural Strength Test

The flexural strength of the composites was also done by universal testing machine in accordance with the standard of ASTM D790. The speed of the machine is about 2mm/min. The flexural strength of all nine combinations is shown in Fig.3.2.

Impact Strength Test

The izod impact test was conducted to find the impact energy in accordance with the standard of ASTM D256. The impact energy of all nine combinations is shown in Fig.3.3.

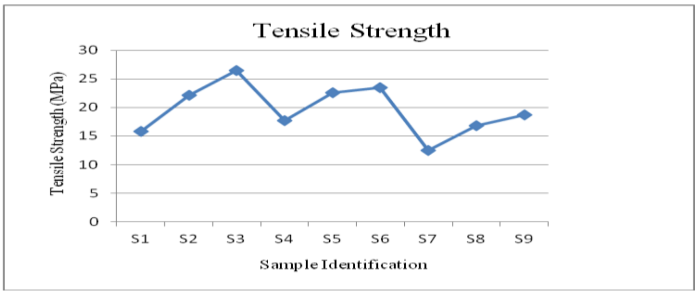


Fig.3.1: Effect of fiber parameters on tensile strength

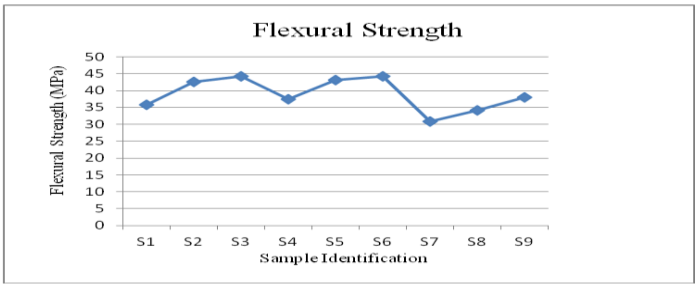


Fig.3.2: Effect of fiber parameters on flexural strength

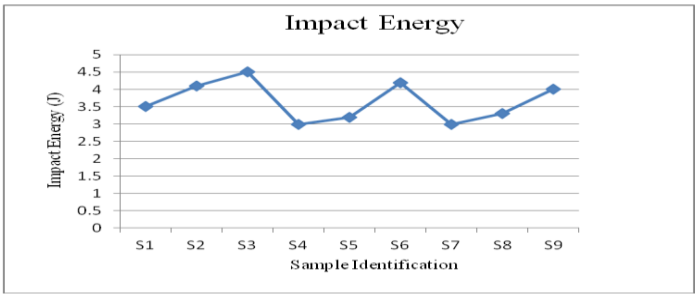


Fig.3.3: Effect of fiber parameters on impact strength

The testing results were tabulated for corresponding fiber weight ratio in Table 3.1.

Table 3.1 Mechanical properties of composites

Sample Identification	A Coir (%)	B Bagasse (%)	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact Energy (J)
S1	10	10	15.83	35.84	3.5
S2	20	10	22.13	42.64	4.1
S3	30	10	26.45	44.31	4.5
S4	10	20	17.69	37.36	3.0
S5	20	20	22.6	43.12	3.2
S6	30	20	23.42	44.2	4.2
S7	10	30	12.52	30.84	3.0
S8	20	30	16.83	34.18	3.3
S9	30	30	18.72	37.98	4.0

IV. Factorial Design Method

Factorial design is a systematic method that investigates the effects of two or more factors on the output response process. Each trail or replication of the experiment takes into account all the possible combinations of the varying levels of these factors.

In this case, two factors (wt% of coir and wt% of bagasse fibers) are the parameters with three levels (-1,0,1) in each factor, so totally 3 x 3 = 9 runs(experiments) were conducted for studying the influence on the response of tensile, flexural and impact strengths. The running of factorial combinations and the mathematical interpretation of the output responses of the process to such combinations is the essence of factorial experiments. It allows an engineer to understand which factors affect the process most, so that improvements may be attained. Fig.4.1 shows the optimum fiber parameter values obtained from factorial design method for tensile, flexural and impact strengths.

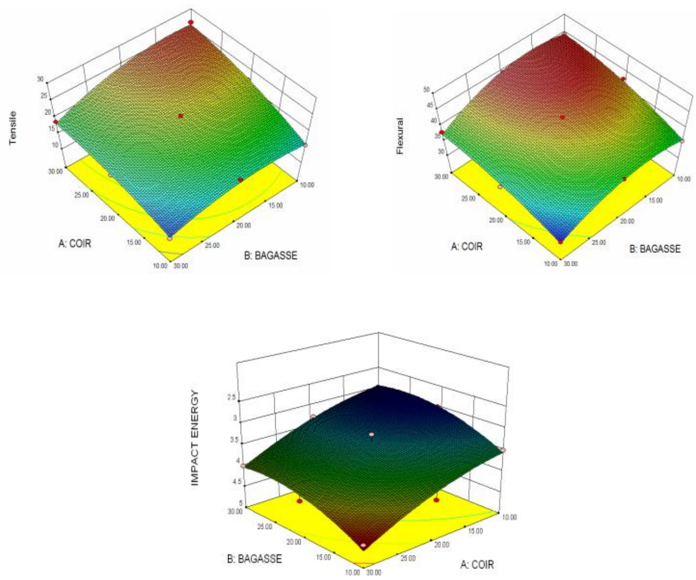


Fig.4.1: Optimum fiber parameter values obtained from factorial design method

V. Analysis of Variance

ANOVA technique can be used to investigate any number of factors which are hypothesized or said to influence the dependent variable. This design consisted of two factors, each at three levels.

ANOVA for Tensile Strength Test

The list of degrees of freedom, sum of squares and mean square for tensile strength model are given in Table 5.1. The Model F-value of 32.18 implies the model is significant. There is only a 0.83% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant.In this case A, B, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

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ANOVA for Flexural Strength Test

The list of degrees of freedom, sum of squares and mean square for flexural strength model are given in Table 5.2. The Model F-value of 31.56 implies the model is significant. There is only a 0.85% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, B2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

ANOVA for Impact Test

The list of degrees of freedom, sum of squares and mean square for impact strength model are given in Table 5.3. The Model F-value of 15.00 implies the model is significant. There is only a 2.47% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

VI. Non-Linear Regressive Analysis

The mechanical properties such as tensile and flexural strength were modeled using second-order polynomial curve fitting equations using Design Expert statistical software. Equation (1) - (3) are the developed non-linear regression models of tensile strength (TS), flexural strength (FS) and impact energy (IE) respectively.

$$TS = 0.07 + 1.16283\,A + 0.94467\,B - 0.01105\,AB - 0.01415\,A^2 - 0.0249\,B^2 \quad (1)$$

$$FS = 18.43556 + 1.064\,A + 1.308\,B - 0.003325\,AB - 0.015583\,A^2 - 0.039283\,B^2 \quad (2)$$

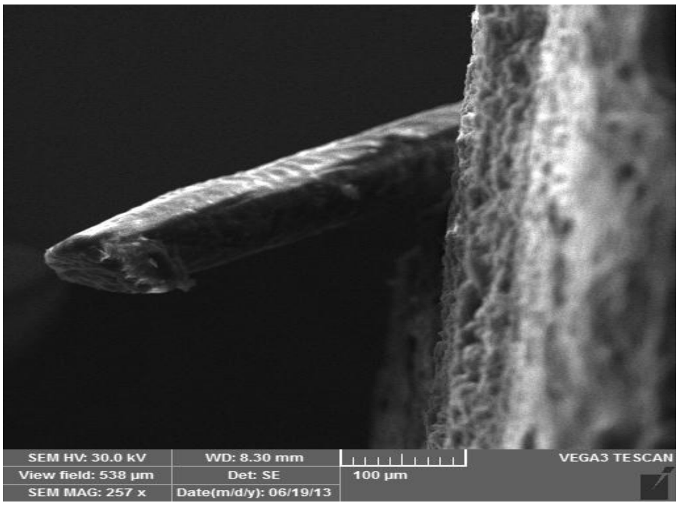
$$IE = 4.62222 - 0.013333\,A - 0.13667\,B - 3.1225E^{-018}\,AB + 0.00167\,A^2 + 0.00267\,B^2 \quad (3)$$

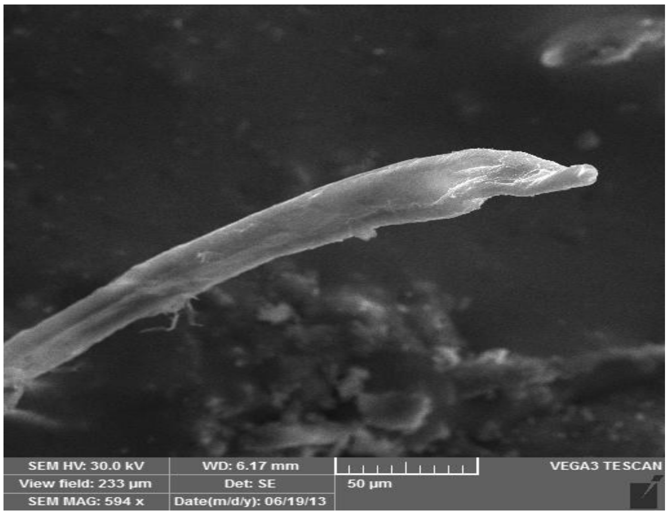
VII. Scanning Electron Microscopy

The Scanning Electron Microscopy testing was conducted on a tensile test specimen to find the fiber matrix interfacial adhesion. The SEM testing morphology images are as follows. The testing was conducted in various higher magnifications of 100µm, 50µm, 20µm and 10µm. The tensile testing specimens were used for testing.

The SEM images represented for coir and bagasse in tensile testing specimen are shown in Fig.7.1 & 7.2 respectively. From these images, it is cleared that there is no pull out holes on the specimens. Instead of that the breaking of fibers only found out. So, the bonding between fibers and polyester resin was extremely high. That bonding could not break up while tensile loading.

Instead of pull out holes, the fiber breaking only occurred during the tensile loading. So, the interfacial bonding adhesion between the fiber and polymer matrix was considerably good while in tensile loading conditions.





VIII. Conclusion

Thus the comparison of tensile, flexural and impact strength for different combination of coir and bagasse fiber contents with polymer resin were done and the optimal mixing of fibers weight ratio were calculated for the effective tensile strength, flexural strength and the impact energy. In this present work, we found out that the 30% of coir fiber and 10% of bagasse fiber with 60% of polyester resin resulted the best values of tensile strength, flexural strength and impact energy i.e., 26.45 MPa, 44.31 MPa and 4.5 J. Here, the second-order polynomial curve fitting equations were modelled which predicts the values of tensile, flexural and impact strengths with various other combination of fibers contents with resin. From the SEM test, it is cleared that there is no pull out holes on the specimens. Instead of that the breaking of fibers only found out. Thus the bonding between fibers and polyester resin was extremely high.

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First and foremost we express our sincere thanks to our parents for their blessings in every step. We extend our heartfelt thanks to all our staff members and friends those who are contributing moral support and encouragement to do this work. We also thank all those who have directly involved or indirectly helped for the successful completion of this research work.

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Table 5.1 ANOVA for tensile strength model

Response	1	Tensile Strength				
ANOVA for Response Surface Quadratic Model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	Sum of Squares	df	Mean square	F value	p-value Prob > F	
Model	150.54	5	30.11	32.18	0.0083	significant
A-COIR	*84.75*	1	84.75	90.57	0.0025	
B-BAGASSE	44.50	1	44.50	47.56	0.0062	
AB4.88	4.88	1	4.88	5.22	0.1065	
A^2*4.00*	4.00	1	4.00	4.28	0.1304	
B^2*12.40*	12.40	1	12.40	13.25	0.0357	
Residual	2.81	3	0.94			
Cor Total	153.35	8				

Table 5.2 ANOVA for flexural strength model

Response	2	Flexural Strength				
ANOVA for Response Surface Quadratic Model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	Sum of Squares	df	Mean square	F value	p-value Prob > F	
Model	185.44	5	37.09	31.56	0.0085	significant
A-COIR	*84.00*	1	84.00	71.48	0.0035	
B-BAGASSE	65.27	1	65.27	55.55	0.0050	
AB	0.44	1	0.44	0.38	0.5830	
A^2	4.86	1	4.86	4.13	0.1350	
B^2	30.86	1	30.86	26.26	0.0144	
Residual	3.53	3	1.18			
Cor Total	188.96	8				

Table5.3 ANOVA for impact energy model

Response	3	Impact Energy				
ANOVA for Response Surface Quadratic Model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	Sum of Squares	df	Mean square	F value	p-value Prob > F	
Model	2.44	5	0.49	15.00	0.0247	significant
A-COIR	1.71	1	1.71	52.36	0.0054	
B-BAGASSE	0.54	1	0.54	16.57	0.0268	
AB	0.000	1	0.000	0.000	1.000	
A^2	0.056	1	0.056	1.70	0.2828	
B^2	0.14	1	0.14	4.36	0.1279	
Residual	0.098	3	0.033			
Cor Total	2.54	8				